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RELATIVE CONTRIBUTIONS OF NUTRIENTS TO THE POTOMAC RIVER BASIN FROM VARIOUS SOURCES

Norbert A. Jaworski, et al

Federal Water Pollution Control Administration
Annapolis, Maryland

January 1970

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RELATIVE CONTRIBUTIONS OF NUTRIENTS TO THE POTOMAC RIVER BASIN FROM VARIOUS SOURCES*

Technical Report No. 31

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and
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January 1970

* Presented at the Cornell Agricultural Waste Management Conference, January 19-21, 1970, Rochester, New York

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INTRODUCTION

The upper Potomac estuary is highly eutrophic. During the summer months, large blooms of nuisance blue-green algae, mainly microcystis, occur in the fresh water portion of the upper estuary. A relationship between high nutrient content and the accelerated eutrophication in the Potomac estuary has been established [1].

To aid in developing the water resources of the Potomac River Basin, an investigation was initiated in 1966 to determine nutrient sources including temporal and spatial distributions. The analyses was expanded in 1968 to determine the amount of nutrients entering the Potomac Basin from all major wastewater discharges. The scope of the program was expanded to include several other basins in the Middle Atlantic Region during 1969.

A DESCRIPTION OF THE POTOMAC RIVER BASIN

The Potomac River Basin has a drainage area of 14,670 square miles and encompasses parts of Pennsylvania, Maryland, West Virginia, and Virginia and all of the District of Columbia. The major sub-basins, including their drainage areas, are:

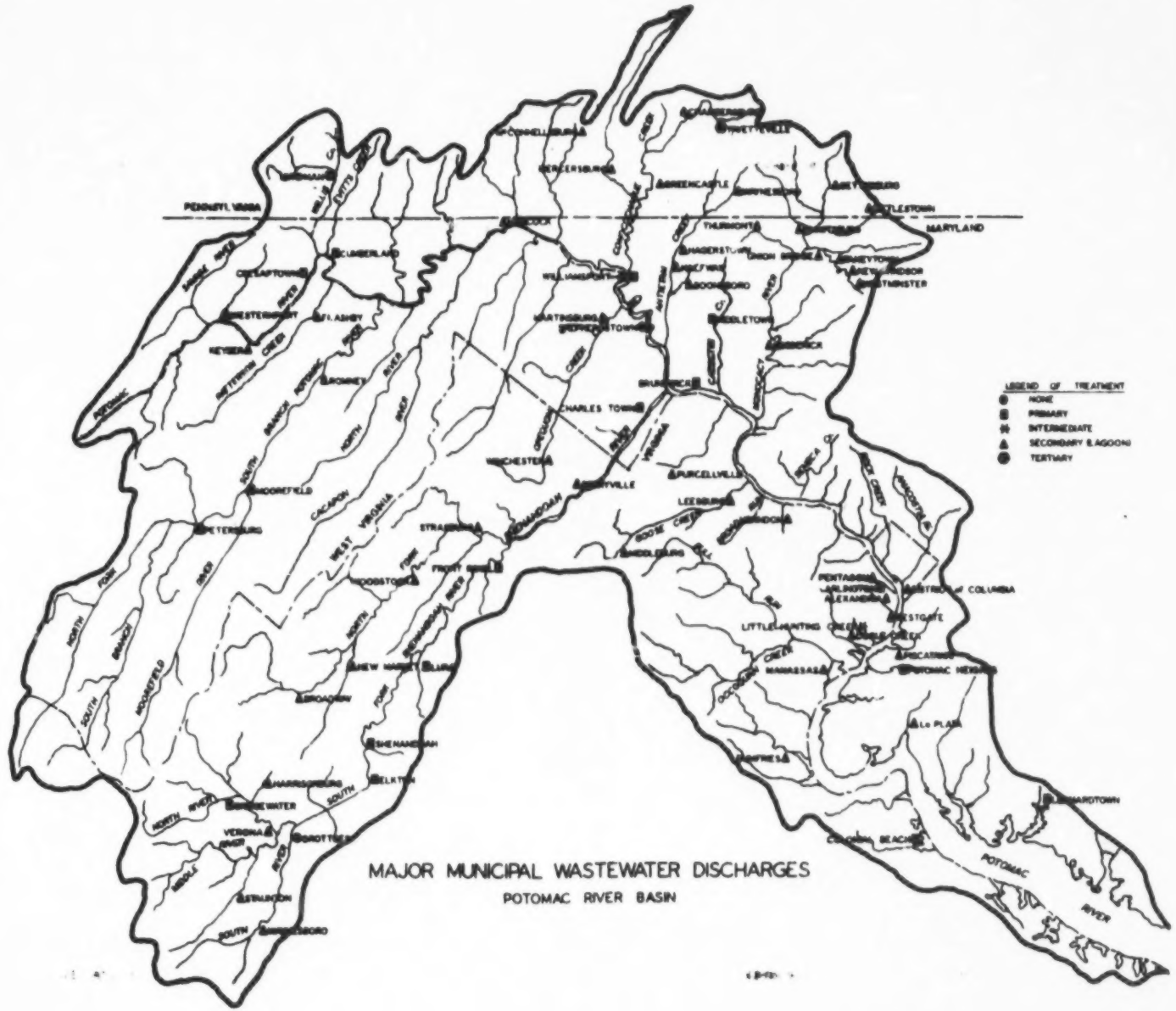
Sub-Basin		Drainage Area (square miles)
(1)	Shenandoah River	3,054
(2)	South Branch	1,493
(3)	North Branch	1,328
(4)	Monocacy River	970
(5)	Cacapon River	683
(6)	Conococheague Creek	563
(7)	Opequon Creek	345
(8)	Antietam Creek	292

A map of the basin is presented in Figure I.

Of the 3 million people living in the basin, about 2.5 million, or 83 percent, live in the Washington, D. C. metropolitan area. The industrial development is primarily concentrated in the North Branch of the Potomac near Luke and Cumberland, Maryland, and in the South Fork of the Shenandoah near Front Royal and Waynesboro, Virginia.

Land use in the sub-basins is either predominately forest, agricultural or urban. In the entire Potomac Basin, it has been estimated that the land use is 5 percent urban, 55 percent forest and 40 percent agricultural including pasture lands.

The Potomac and its tributaries are characterized by flash floods and extremely low flows. The average discharge of the Potomac River at Washington, D. C. is about 11,000 cubic feet per second (cfs).



MAJOR MUNICIPAL WASTEWATER DISCHARGES

POTOMAC RIVER BASIN

Figure 1

NUTRIENT SOURCES

A. Sampling Programs

During the 1966 calendar year, a 40-station stream sampling network was monitored weekly for nitrogen and phosphorus as shown in Figure 2. Weekly analyses of nutrients from 13 wastewater discharges in the upper basin were initiated during the latter part of 1966.

During 1968, all municipal and all bio-degradable industrial wastewater discharges with a flow greater than 0.5 million gallons per day (mgd) were sampled.

In 1969, a sampling network, as shown in Figure 3, was developed to determine the nutrient loading into the Chesapeake Bay. The weekly analysis included two forms of carbon, three of phosphorus and four of nitrogen taken at sampling stations just above the non-tidal portions of the respective basins.

NUTRIENT NETWORK
POTOMAC RIVER BASIN

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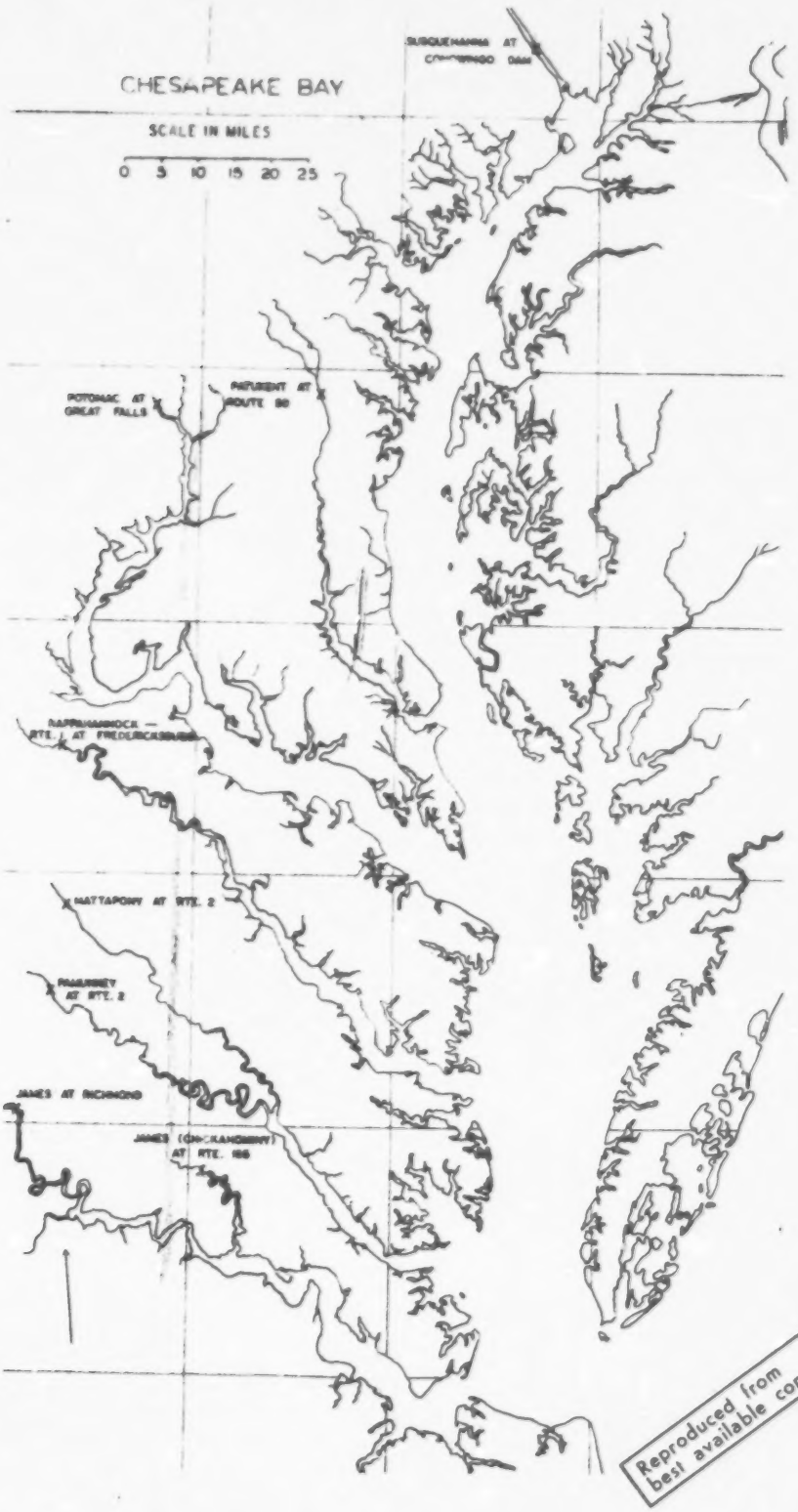
Figure 2

CHESAPEAKE BAY NUTRIENT INPUT STATIONS


CHESAPEAKE BAY
SCALE IN MILES
0 5 10 15 20 25
POTOMAC AT GREAT FALLS
PATUXENT AT ROUTE 50
RAPPAHANNOCK — RTE. 1 AT FREDERICKSBURG
MATTAPONY AT RTE. 2
PAMUNKEY AT RTE. 2
JAMES AT RICHMOND
JAMES (APPOMATTOX) AT RTE. 156

Reproduced from best available copy.

FIGURE 3

B. Wastewater Loadings in the Potomac Basin

As of December 1968, there were about 380 wastewater discharges in the upper Potomac River basin. During 1968, 80,430 lbs/day of total phosphorus and 63,680 lbs/day total Kjeldahl nitrogen were discharged to the surface waters. As can be seen in Table I, the largest contribution to the Potomac estuary is from the Washington, D. C. area. For a sewered population of 2,903,500, this reduces to 0.024 and 0.020 lbs/capita/day of phosphorus and nitrogen, respectively.

Nutrient loadings from industrial wastewater discharges are about 7,700 lbs/day of total PO_4 and 4,600 lbs/day of TKN. The industrial contributions to wastewater nutrient loadings in the basin are about 10 percent of the total PO_4 (TPO_4) and about 7 percent of the total nitrogen. The amount of NO_2+NO_3 nitrogen in both the industrial and municipal wastewater discharges is insignificant.

TABLE I

NUTRIENT LOADINGS FROM WASTEWATER DISCHARGES
BY SUB-REGIONS*

Sub-Region	Population Served	LOADING AFTER TREATMENT BOD lbs/day	TKN lbs/day	TPO_4 lbs/day
North Branch	79,200	55,300	1,750	4,850
South Branch and Upper Region	17,300	2,720	370	460
Opequon	34,800	3,470	480	1,100
Conococheague and Upper Middle Region	26,900	4.250	710	1,050
Antietam and Middle Region	61,500	7,980	890	2,380
Shenandoah	108,500	31,800	4,890	6,360
Catoctin Creeks Md. and Va.	5,400	740	110	220
Monocacy	62,500	4,220	1,380	1,830
Lower Fresh Water Region	7,400	200	100	180
Potomac Estuary	2,500,000	130,000	53,000	62,000
TOTAL	2,903,500	240,680	63,680	80,430

* A Sub-region may include discharges to the small tributaries and to the main stem of the Potomac.

C. Land Runoff and Other Sources

To determine the amount of nutrients entering the Potomac from land runoff, analyses of loadings from areas with three distinct land uses (forest, agricultural, and urban) were made [2]. Using the Catoctin Creek (Maryland) watershed basin as primarily agricultural, the Patterson Creek watershed as forested, and Rock Creek watershed as urban, the effect of land uses on the contribution of nutrients to surface waters is illustrated in Figures 4 and 5. These three areas receive a relatively small wastewater volume.

On an annual basis, the concentration of nutrients was consistently higher from agricultural areas. As summarized in Table II, it can be seen that the runoff from agricultural areas yields about twice the nitrogen and phosphorus as does the forested area.

Summary of the nutrient data for the major sub-basins, as presented in Table III, indicates that the phosphorus concentrations were at least three times greater in the Monocacy River, Opequon Creek, and Antietan Creek sub-basins than in the remaining five sub-basins. These three sub-basins, while primarily agricultural, also receive considerable quantities of municipal wastewater. These higher concentrations are also reflected in large PO_4 yields of from 3.6 to 4.8 lbs/day/sq. mi., as shown in Table III.

The Conococheague, Antietam, Opequon, and Monocacy sub-basins had average concentrations of NO_2+NO_3 nitrogen of 1.4 mg/l and greater. The Conococheague and Monocacy sub-basins had nitrite and nitrate yields of over 10 lbs/day/sq.mi., almost twofold larger than that of the remaining four sub-basins. This is mainly from agricultural drainage.

LAND USE COMPARISON

TOTAL PHOSPHORUS PO_4

POTOMAC RIVER BASIN

1966

WATERSHED	% FOREST	% FARM	% URBAN
PATTERSON Ck.	88	12	0
CATOCTIN Ck., Md.	20	80	0
ROCK Ck.	10	30	60

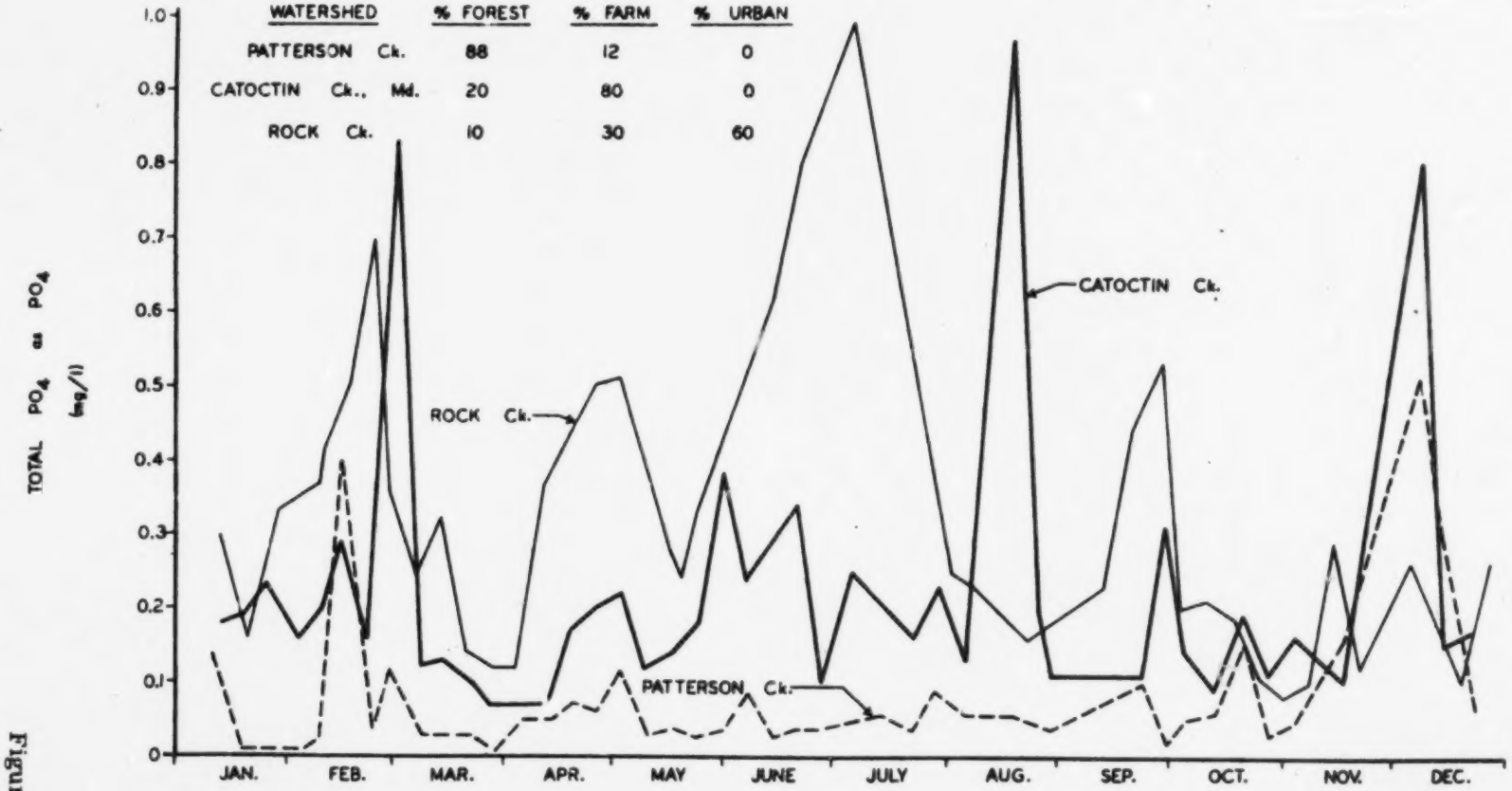


Figure 4

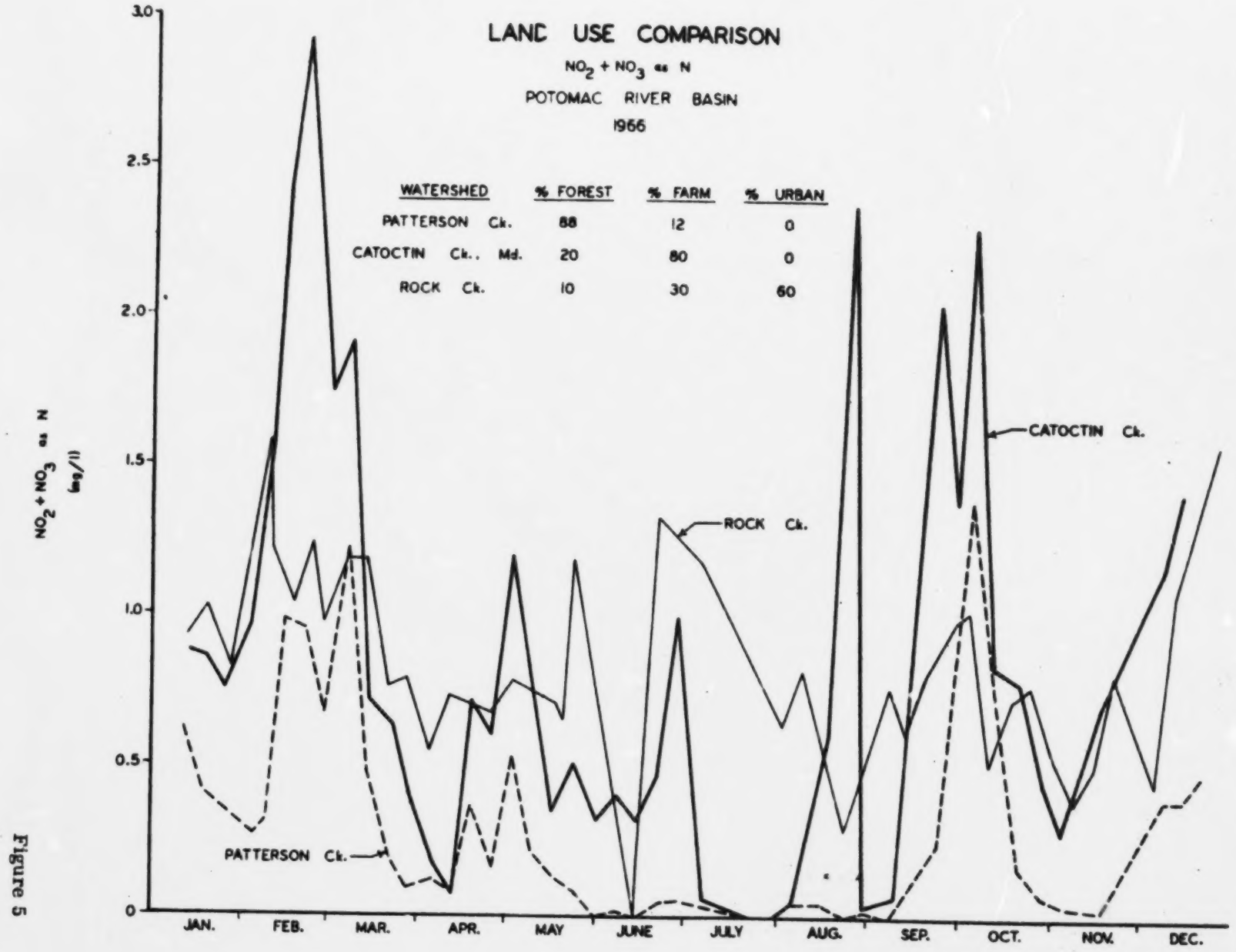

LAND USE COMPARISON
$NO_2 + NO_3$ as N
POTOMAC RIVER BASIN
1966
WATERSHED | % FOREST | % FARM | % URBAN
PATTERSON Ck. | 88 | 12 | 0
CATOCTIN Ck., Md. | 20 | 80 | 0
ROCK Ck. | 10 | 30 | 60
$NO_2 + NO_3$ as N (mg/l)
3.0
2.5
2.0
1.5
1.0
0.5
0
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEP.
OCT.
NOV.
DEC.
CATOCTIN Ck.
ROCK Ck.
PATTERSON Ck.

Figure 5

TABLE II

NUTRIENT LOADINGS FROM WATERSHEDS WITH VARYING LAND USE

1966 Data

Watershed and Land Use	Drainage Area (sq.mi.)	TPO_4 as PO_4 (lbs/day/sq.mi.)	NO_2+NO_3 as N (lbs/day/sq.mi.)	TKN as N (lbs/day/sq.mi.)
Patterson Creek (Forest)	279	0.5	2.0	0.4
Catoctin Creek (Agric.)	109	1.3	6.0	0.7
Rock Creek (Urban)	77	1.1	2.7	0.7

TABLE III

COMPARISON OF ANNUAL AVERAGE NUTRIENT CONCENTRATIONS AND LOADINGS
1966

Major Sub-basins of Upper Potomac River Basin

Sub-basin (Station)	Drainage Area (sq.mi.)	TPO_4 as PO_4 (mg/l)	TPO_4 as PO_4 (lbs/day)	TPO_4 as PO_4 (lbs/day/sq.mi.)	NO_2+NO_3 as N (mg/l)	NO_2+NO_3 as N (lbs/day)	NO_2+NO_3 as N (lbs/day/sq.mi.)	TKN as N* (mg/l)
North Branch (Oldtown, Md.)	1,328	.532	2,551	1.92	.378	3,267	2.46	.784
South Branch (Romney, W.Va.)	1,450	.092	1,535	1.06	.296	3,655	2.52	
Conococheague Cr. (Williamsport, Md.)	469	.327	1,226	2.61	1.593	5,317	11.34	.019
Antietam Creek (Antietam, Md.)	283	1.996	1,353	4.78	1.429	1,321	4.67	.536
Opequon Creek (Martinsburg, W.Va.)	309	1.511	1,109	3.59	2.149	1,817	5.88	.264
Shenandoah River (Bloomery, W.Va.)	3,012	.356	5,105	1.69	.654	6,714	2.23	.580
Monocacy River (Frederick, Md.)	813	1.176	3,385	4.16	1.744	8,661	10.65	.693
Potomac River (Great Falls, Md.)	11,460	.379	17,013	1.48	.903	49,009	4.28	.270

* Based on 6 months of sampling

The large variations in NO_2+NO_3 nitrogen can be attributed to high mobility of NO_3 ion as reported by Wadleigh [3] and Bailey [4]. Figure 6 for the South Branch station at Petersburg demonstrates that the concentration of nitrates is directly related to river discharge while concentrations of TKN and PO_4 are indirectly related.

For the 35 stations in the non-tidal portion of the basin, regression analyses were made using both linear and log transforms [5]. The log transforms appeared to yield the best correlation resulting in the following expression:

$$C = aQ^b$$

where:

C = concentration of PO_4, TKN, or NO_2+NO_3 (mg/l)

Q = stream flow (cfs)

a = a constant

b = an exponent

Using the slope of the concentration-discharge relationship (the exponent b) and knowing the specific location of the sampling point in relation to the municipal or industrial waste outfalls, a quantization of the sources of the nutrients can be obtained. For example, all stations, except one below an industrial outfall discharging nitrates, had a positive slope ranging from about 0.3 to 0.7 with an average of 0.5 suggesting that most of the inorganic nitrogen comes from land and other sources and not from wastewater discharges.

SOUTH BRANCH POTOMAC RIVER

AT

PETERSBURG, WEST VIRGINIA

TKN, $NO_2 + NO_3$ and PO_4 Vs. RIVER DISCHARGE

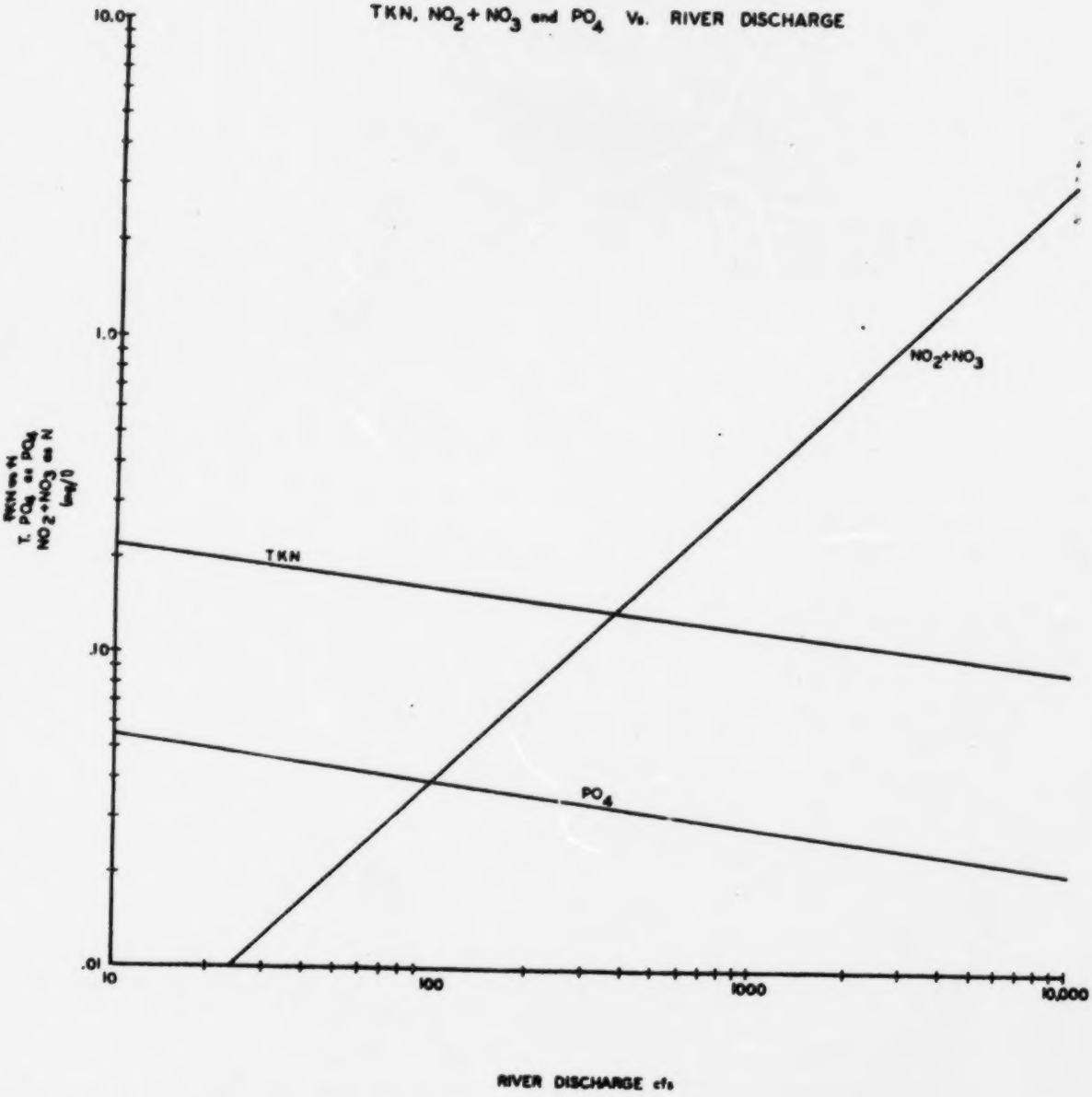


Figure 6

The concentrations of phosphorus and TKN for most of the non-tidal stations had either slightly positive or negative slopes indicating a diluting effect. The correlation coefficients for these two parameters were low, probably due to seasonal and flushing effects which were not incorporated into the regression studies.

A review of the slopes of the concentration-flow relationships for stations above and below waste outfalls definitely supports the findings of Bailey [4] who indicated that (1) nitrate nitrogen has high mobility in soil, (2) PO_4 and TKN are not readily leached, and (3) nutrient concentrations appear to be affected by stream transport mechanisms.

Using the same land use designations that the U. S. Corps of Engineers developed in their 1958 study [6], the nutrient loading from land runoff was determined (Table IV). It should be noted that the largest contribution of nutrients, about 65 percent, is from agricultural runoff even though only 38 percent of the basin is farmed or in pasture lands.

TABLE IV

ESTIMATED NUTRIENT LOADINGS FROM LAND RUNOFF

Potomac River Basin
1966

Land Use	Area	TPO_4 as PO_4		NO_2+NO_3 as N		TKN as N	
	(sq mi)	(lbs/day/sq mi)	(lbs/day)	(lbs/day/sq mi)	(lbs/day)	(lbs/day/sq mi)	(sq mi)
Agriculture*	5,840	1.3	7,592	6.0	35.040	0.7	4,088
Forest	8,100	0.5	4,050	2.0	16,200	0.4	3.240
Urban	730	1.1	800	3.0	2,190	0.7	511
Total Basin	14,670	0.84	12,442	4.98	53,430	0.53	7,839

*Agricultural use includes both crop land and pastures.

D. Relative Contribution of Loadings

Utilizing the wastewater data of 1968 and stream flow conditions of 1966, the total nutrient loadings to the surface waters of the basin have been estimated as presented in Table V. The delineation of the sources indicates the following:

1. Of the 92,872 lbs/day of total phosphorus as PO_4, 87 percent was from wastewater discharges.
2. About 67 percent of the total phosphorus was from wastewater discharges in the upper Potomac estuary.
3. The total loading of nitrogen as N was about 125,000 lbs/day, of which approximately 51 percent or 63,680 lbs/day originated from wastewater discharges.
4. About 43 percent of the total nitrogen loading was from wastewater discharges in the upper Potomac estuary.

The above delineation clearly indicates for the Potomac River basin the major sources of phosphorus is from wastewater. The major source of nitrogen in 1966 was also from wastewater discharge. Land runoff from the agricultural areas had the highest yield of nitrogen per square mile. Moreover, the concentration of nitrate-nitrogen appears also to be greatly affected by stream flow conditions.

Data for the first eight months of 1969 indicate that over 80 percent of phosphorus and 66 percent of the nitrogen entering the Potomac estuary was from wastewater discharges in the Washington, D.C. area [7]. Even though the first six months of 1969 had stream flows

below normal with the latter period having above or normal flow conditions, the data supports the 1966 findings that the major source of nutrients in the Potomac is from wastewater discharges.

TABLE V

ESTIMATED TOTAL POTOMAC BASIN NUTRIENT LOADING
1966

Source	TPO_4 as PO_4 (lbs/day)	% of total	NO_2+NO_3 as N (lbs/day)	% of total	TKN as N (lbs/day)	% of total
Wastewater	80,430	87	*		63,680	89
Land Runoff	12,442	13	53,430	100	7,839	11
Total Basin	92,872	100	53,430	100	71,519	100

* The amount of NO_2+NO_3 Nitrogen in the wastewater was insignificant.

E. Temporal Variations

An important aspect of the nutrient control problem is the annual variation in nutrient contributions from the various sources, especially from land runoff. The nitrate-nitrogen loadings from the years 1947-1967 for the Potomac River at Great Falls show a definite seasonal pattern (Figure 7). The seasonal loading variations closely parallel those of river discharge that is high in the spring months, low in the summer and fall, and somewhat higher than fall in the winter months.

The relationship between river discharge and nutrient loadings is vividly demonstrated in Figure 8 for the Potomac at Great Falls. During the high discharge rate in February and March of 1966, the NO_2+NO_3 and TPO_4 loadings were also the largest while in August, when the flow was very low, the nutrient loadings were likewise small.

In mid-September of 1966, there was considerable precipitation throughout the basin. This resulted in a high nutrient loading in September as also seen in Figure 8.

An important aspect of the temporal variations in nutrient loadings is nutrient transport. This is especially pronounced for phosphorus. As can also be seen in Figure 8, during August less than 100 lbs/day of TPO_4 entered the estuary even though over 18,400 lbs/day were discharged to surface waters from wastewater discharges. During low flow conditions, considerable amounts of phosphorus in the surface waters are either precipitated, adsorbed

onto sediment particles or utilized by aquatic life. At times of high stream flows, much of the phosphorus is re-suspended and transported downstream.

The high loadings of TPO_4 in mid-September were due to flushing of the river channel system by the high stream flows. The high inorganic nitrogen loadings in September can be readily attributed to flushing of the land as previously indicated.

The various forms of phosphorus and nitrogen for the Potomac River at Great Falls during the first 10 months of 1969 are presented in Figures 9 and 10. Figure 9 shows that only about 25 percent of the total phosphorus is in the dissolved reactive form. This suggests that most of the phosphorus originating from the upper basin was or has become attached to silt particles.

Similar to Figures 6 and 7, the NO_2+NO_3 nitrogen as shown in Figure 10 demonstrates the dependence of this form of nitrogen on river discharge. Fraction analyses of the TKN form indicates that over 50 percent is in the particulate state.

The wide variations in nutrient loadings in the Potomac River at Great Falls demonstrates the need to sample at various river discharges continuously over an annual cycle before a delineation of nutrient sources can be made. Moreover, as shown in Figure 8, sampling only during summer flow conditions can yield misleading conclusions as to the temporal distribution, relative sources and transport mechanism of nutrients.

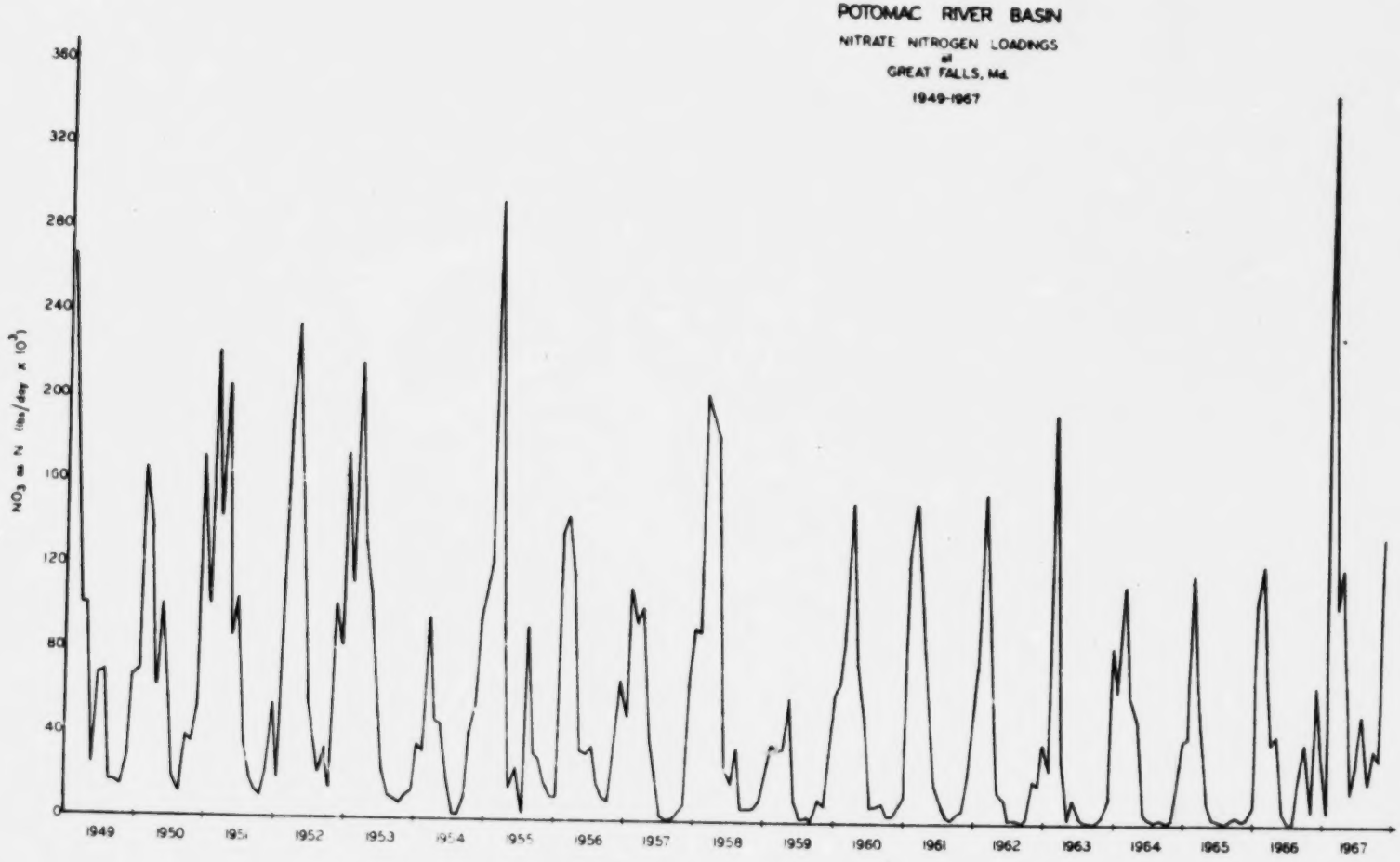

POTOMAC RIVER BASIN
NITRATE NITROGEN LOADINGS
at
GREAT FALLS, Md.
1949-1967
NO_3 as N (lbs/day x 10^3)
360
320
280
240
200
160
120
80
40
0
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967

Figure 7

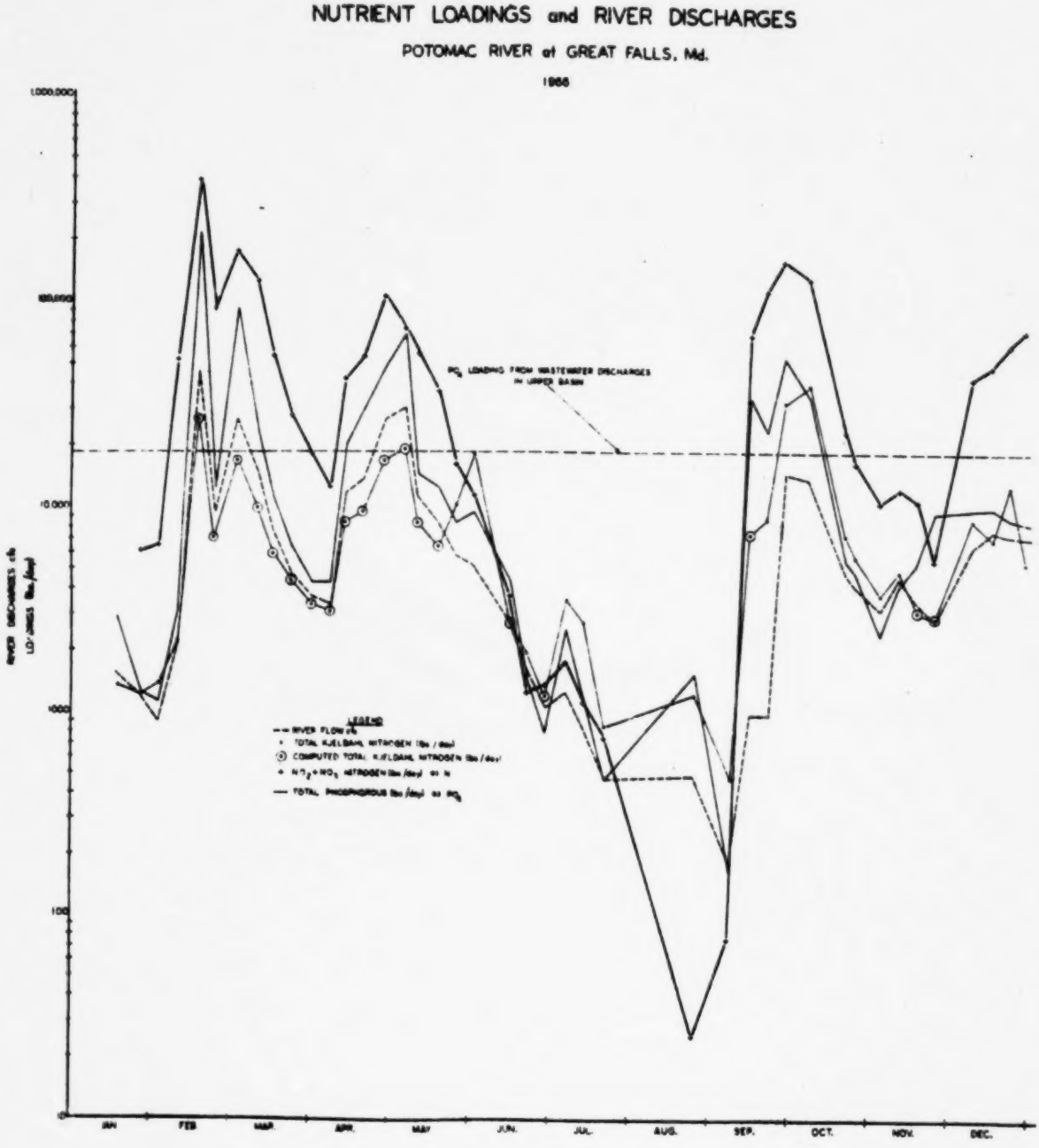

NUTRIENT LOADINGS and RIVER DISCHARGES
POTOMAC RIVER at GREAT FALLS, Md.
1966
LEGEND
TOTAL PHOSPHORUS
JAN
FEB
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.

Figure 8

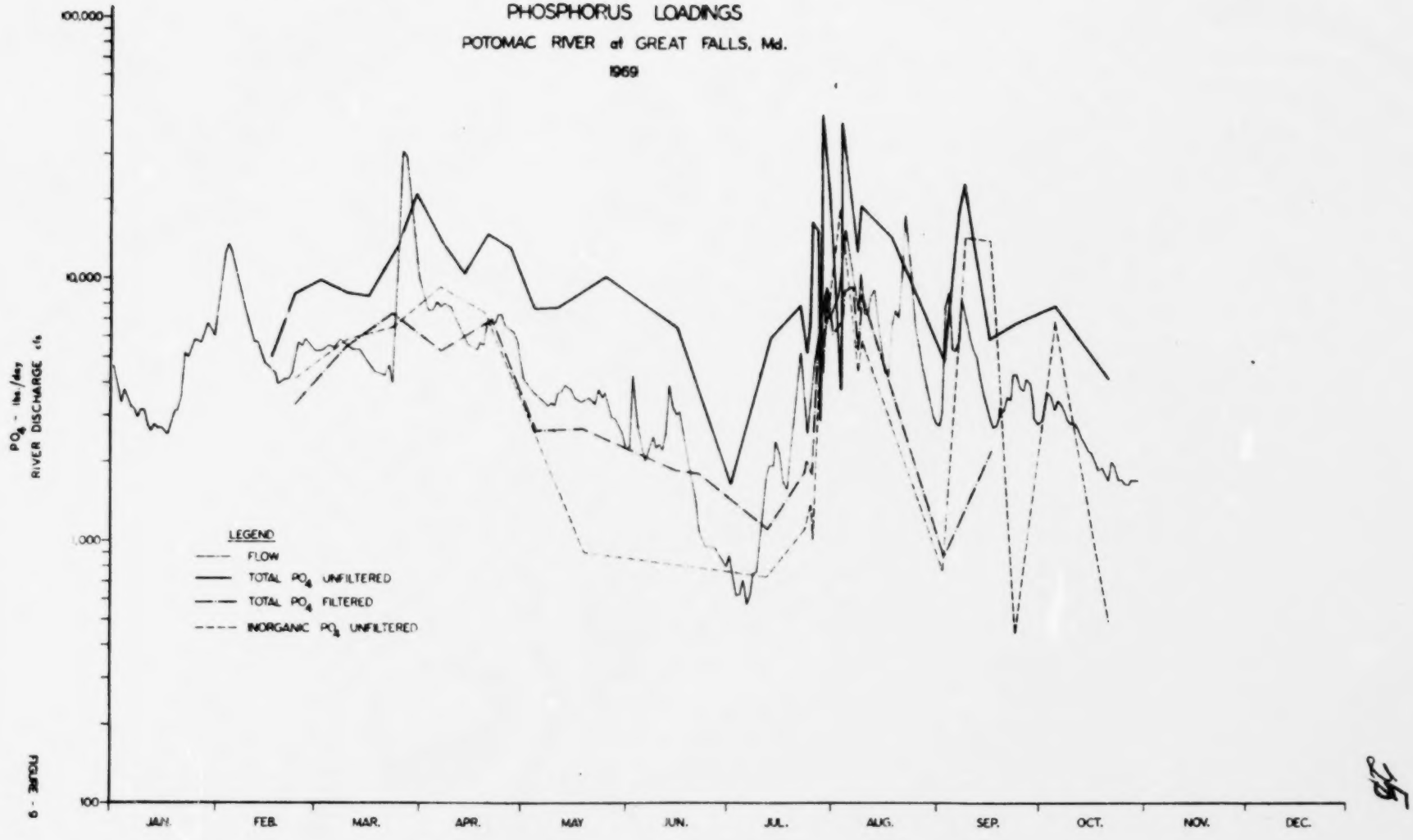

PHOSPHORUS LOADINGS
POTOMAC RIVER at GREAT FALLS, Md.
1969
100,000
10,000
1,000
100
PO4 - lbs/day
RIVER DISCHARGE c/s
LEGEND
FLOW
TOTAL PO4 UNFILTERED
TOTAL PO4 FILTERED
INORGANIC PO4 UNFILTERED
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.

FIGURE - 9

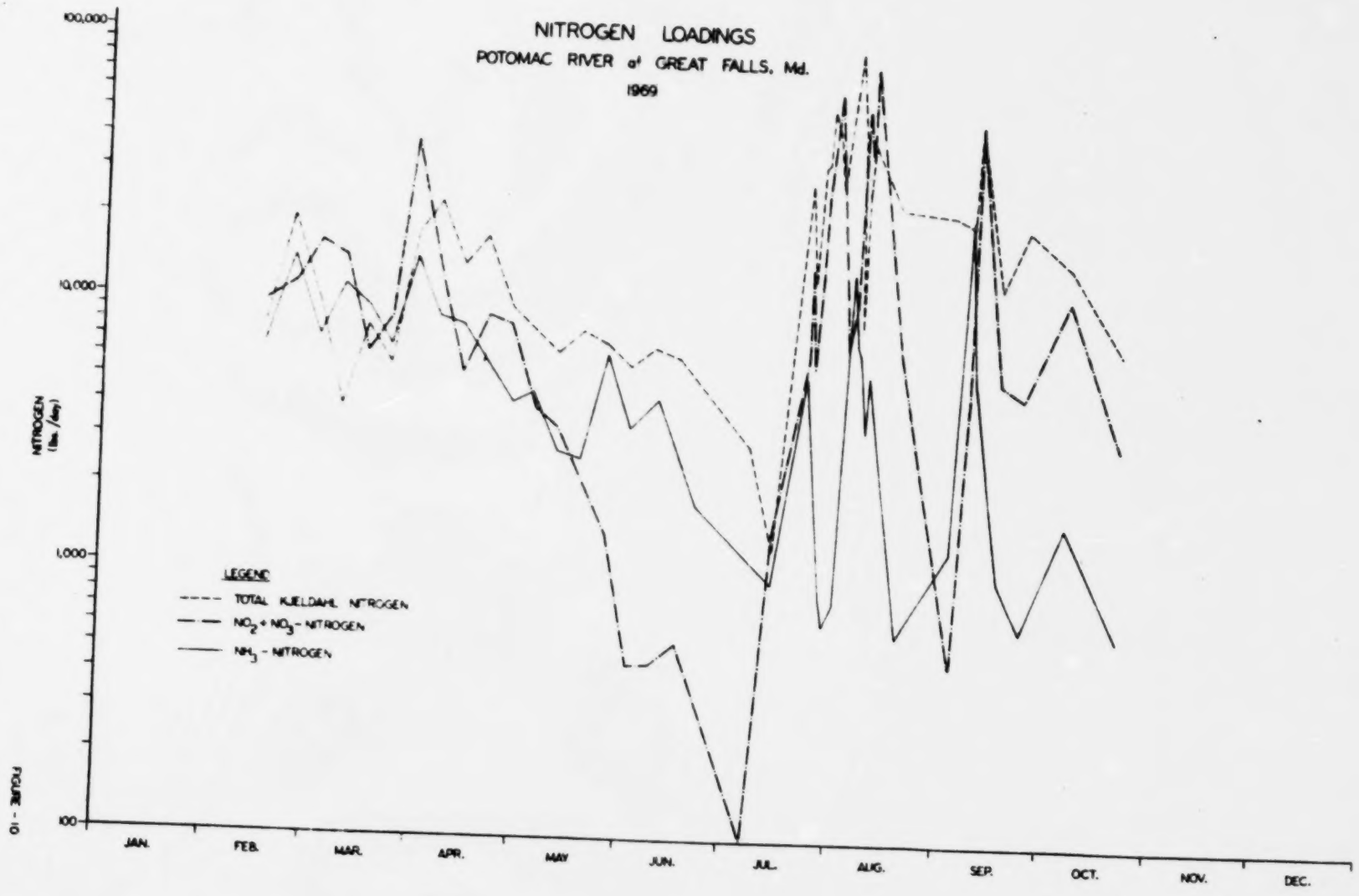

NITROGEN LOADINGS
POTOMAC RIVER at GREAT FALLS, Md.
1969
100,000
10,000
1,000
100
NITROGEN (lbs./day)
LEGEND
TOTAL KJELDAHL NITROGEN
$NO_2 + NO_3$ - NITROGEN
NH_3 - NITROGEN
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.

FIGURE - 10

F. Comparison to Other River Basins in the Middle Atlantic Region

Figures 11, 12 and 13 present a six month comparison of nutrient concentrations for five river basin systems as part of a nutrient input study of the Chesapeake Bay system. The mean monthly concentration of phosphorus is highest for the Patuxent Basin and lowest for the Susquehanna with the Potomac being second highest (Figure 11). Except for the Patuxent, all have concentrations usually less than 0.5 mg/l.

In terms of NO_2+NO_3 nitrogen, the Patuxent is the highest (Figure 12). This is mainly due to high ratio of sewage to stream flow in this small basin. The concentrations, usually less than 0.5 mg/l, were the lowest for the Rappahannock Basin with Potomac being comparable to the other basins of its size, ranging from about 0.5 to 0.75 mg/l.

TKN nitrogen concentrations in the Patuxent were the highest with the Potomac being second highest. For the three remaining basins, the concentration varied from about 0.3 to 1.0 mg/l.

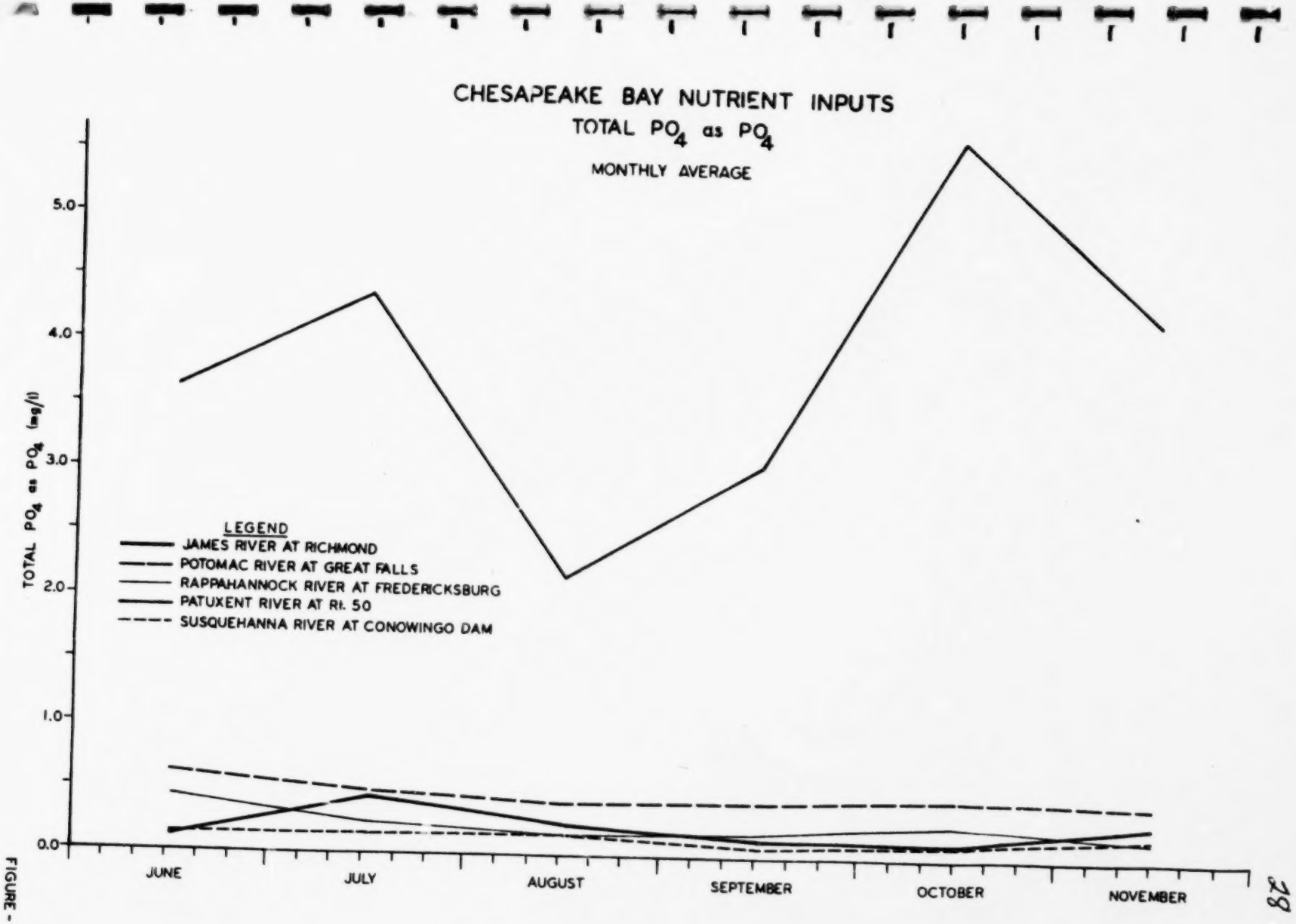

CHESAPEAKE BAY NUTRIENT INPUTS
TOTAL PO_4 as PO_4
MONTHLY AVERAGE
TOTAL PO_4 as PO_4 (mg/l)
5.0
4.0
3.0
2.0
1.0
0.0
LEGEND
JAMES RIVER AT RICHMOND
POTOMAC RIVER AT GREAT FALLS
RAPPAHANNOCK RIVER AT FREDERICKSBURG
PATUXENT RIVER AT Rt. 50
SUSQUEHANNA RIVER AT CONOWINGO DAM
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER

FIGURE - 11

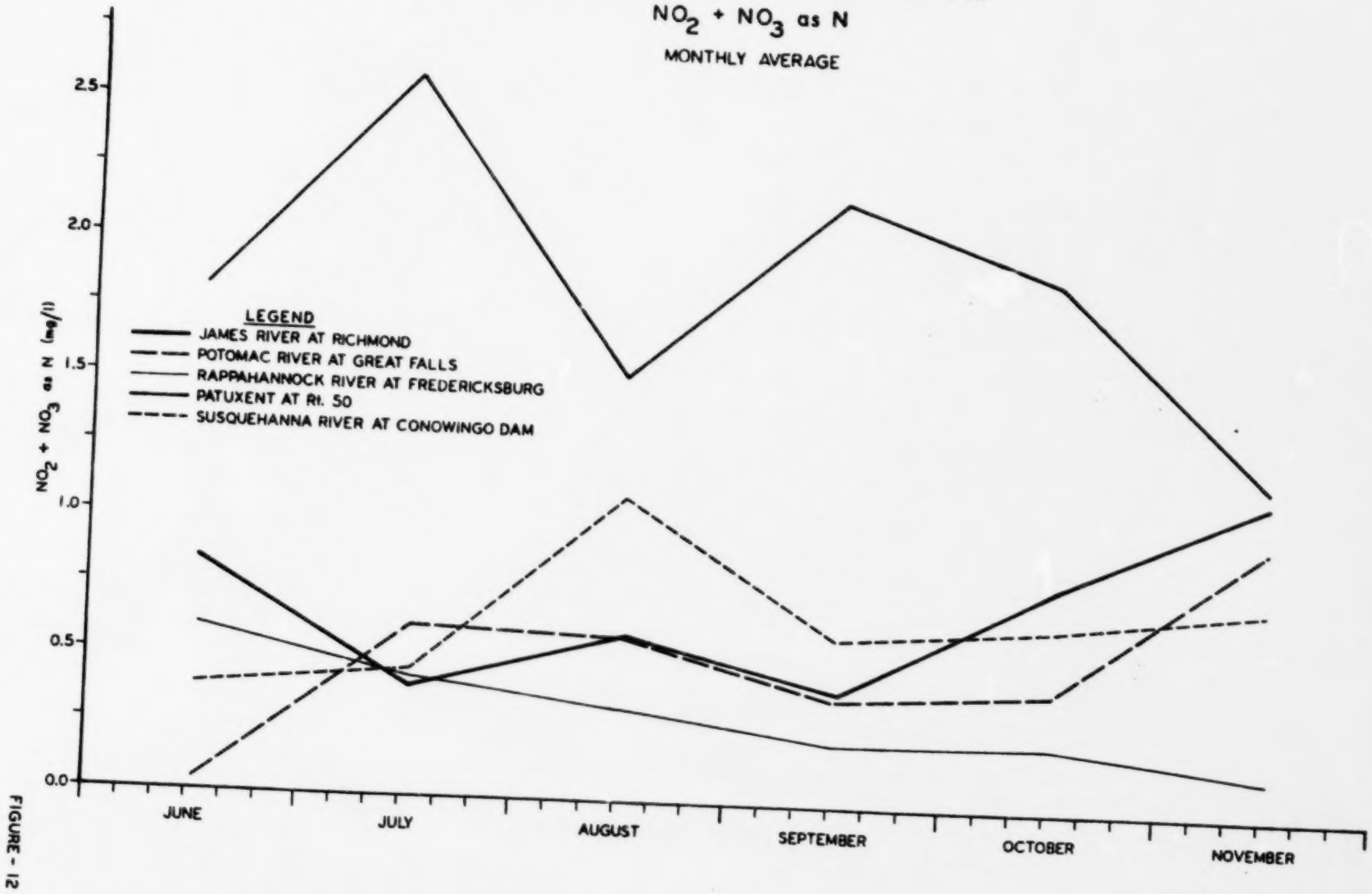

CHESAPEAKE BAY NUTRIENT INPUTS
$NO_2 + NO_3$ as N
MONTHLY AVERAGE
$NO_2 + NO_3$ as N (mg/l)
2.5
2.0
1.5
1.0
0.5
0.0
LEGEND
JAMES RIVER AT RICHMOND
POTOMAC RIVER AT GREAT FALLS
RAPPAHANNOCK RIVER AT FREDERICKSBURG
PATUXENT AT Rt. 50
SUSQUEHANNA RIVER AT CONOWINGO DAM
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER

FIGURE - 12

CHESAPEAKE BAY NUTRIENT INPUTS

TKN as N

MONTHLY AVERAGE

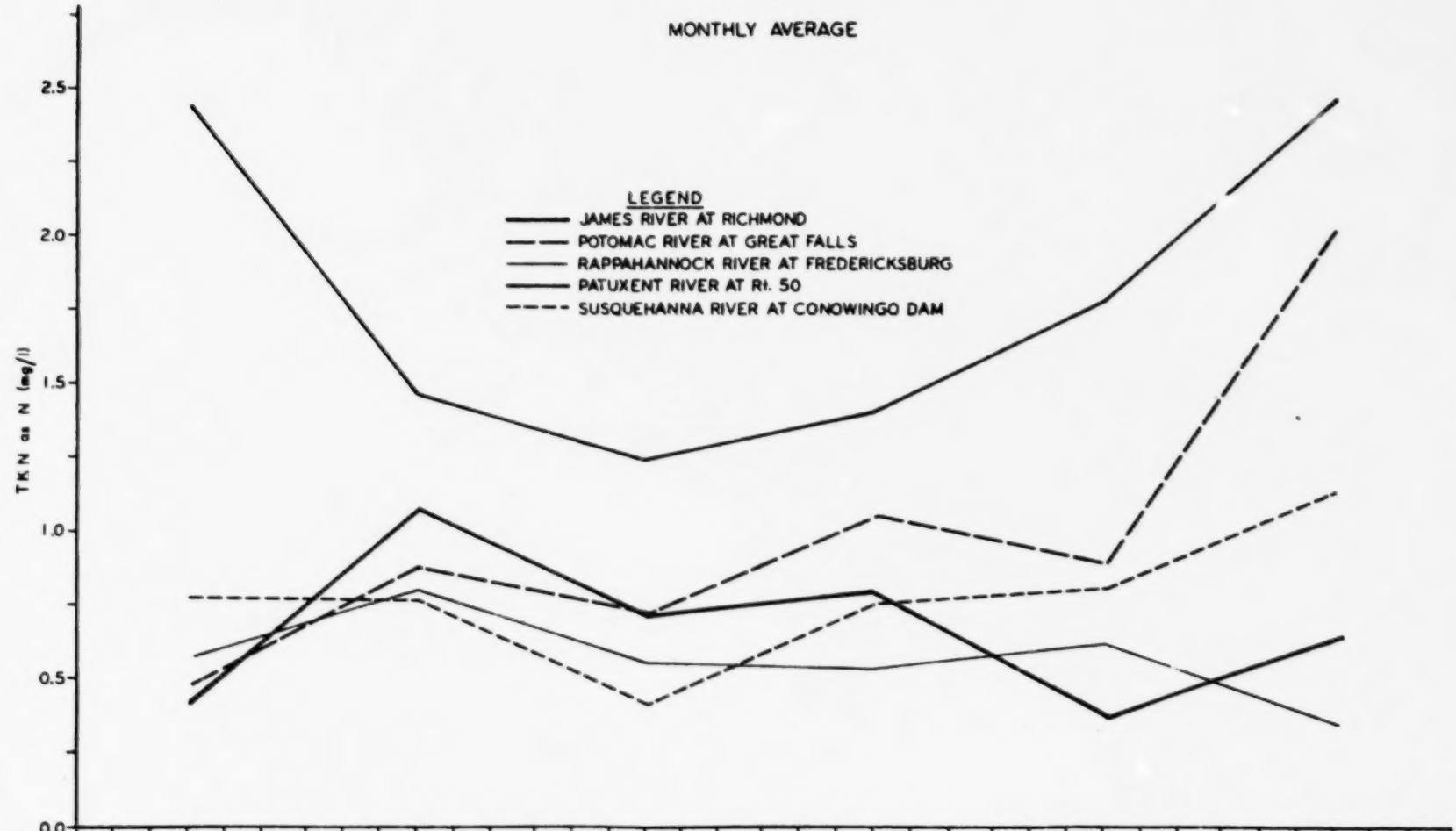


FIGURE - 13

G. Hudson River Basin System

In order to determine if the relatively high percentage of nutrients from wastewater in the Potomac Basin was unique or whether it is more generally true that wastewater discharges are the most significant contributors of nutrients to the aquatic ecosystem in the Middle Atlantic Region, a comparison of the nutrient sources was made for the Hudson River Basin. This basin is relatively comparable to the Potomac in size, land use patterns and population (both over-all density and distribution). It is also more highly industralized.

A complete description of the Hudson River Basin and its nutrient loading was recently presented by Tofflemire and Hetling [8]. As a result of this study, it was estimated that the total phosphorus as PO_4 discharged to the Hudson River Basin above the New York City line is approximately 72,000 lbs/day, 73% of which is from wastewater discharges. The corresponding total for nitrogen as N is 125,570 lbs/day with 63% coming from wastewater.

A comparison of the Hudson River estimates with those found for the Potomac is given in Table VI. The Hudson results give added support to the Potomac findings that, for the large river basins in the Middle Atlantic Region, the major source of nutrients is wastewater discharges.

TABLE VI

COMPARISON OF NUTRIENT LOADINGS
IN HUDSON AND POTOMAC RIVER BASINS

Total Phosphorus as PO_4

Source	Potomac Basin (lbs/day)	%	Hudson Basin (lbs/day)	%
Wastewater	80,430	87	52,000	73
Land Runoff	12,442	13	19,420	37
Total Basin	92,872	100	71,600	100

Total Nitrogen as N

Source	Potomac Basin		Hudson Basin	
Wastewater	63,680	51	78,500	63
Land Runoff	61,269	49	47,070	37
Total Basin	124,949	100	125,570	100

SUMMARY AND CONCLUSIONS

Results of the initial phase of the nutrient investigations in the Potomac River system, which have been expanded to include other river basins and which are being continued by the CTSL, are summarized below:

1. The annual average concentration of phosphorus as PO_4 in the major sub-basins varied from a minimum of 0.09 mg/l in the South Branch to a maximum of 1.9 mg/l in the Antietam watershed.

2. The annual average concentration of NO_2+NO_3 nitrogen as N in the major sub-basins varied from 0.3 mg/l in the South Branch to 2.2 mg/l in Opequon Creek.

3. The annual average concentrations of phosphates, total Kjeldahl nitrogen (TKN) and NO_2+ NO_3 nitrogen in the freshwater stream flow entering the estuary near Washington, D. C., were 0.3, 0.3, and 0.9 mg/l, respectively.

4. About 92,700 lbs/day of total phosphorus as PO_4 entered the surface waters of the Potomac in 1966, of which 87 percent resulted from wastewater discharges.

5. The average 1966 loading of total nitrogen as N from all sources to the surface waters of the basin was about 125,000 lbs/day, of which 63,680 lbs/day, or 51 percent, were from wastewater discharges.

6. Seasonal variations in inorganic nitrogen loadings are much more pronounced when compared to phosphorus. This is mainly attributed

to a direct relationship between stream flow and inorganic nitrogen concentration for the stations in the non-tidal portion of the basin while phosphorus generally has an inverse relationship.

7. From an analysis of watersheds with varying land uses and receiving little or no wastewater discharges, the average annual yields per square mile for the entire basin was 0.8 lbs/day of phosphorus PO_4, 5.0 lbs/day of NO_2+NO_3 nitrogen as N, and 0.5 lbs/day of TKN.

8. Of the 61,270 lbs/day of total nitrogen from land runoff, about 35,000 lbs/day or 65 percent, were from agricultural areas which comprise only 38 percent of the total drainage area in the basin.

9. Nutrient yields were over twofold greater from areas which were predominately agricultural than from forested areas.

10. Similar to 1966 findings, data for the first eight months of 1969 corroborate that the major source of nutrients is from wastewater discharge with the largest contribution originating in the Washington, D. C. area.

11. During low flow conditions a significant proportion of the phosphorus entering the surface water from the various sources in the upper basin is retained in the stream channel. At high stream flow, it appears that a large proportion of this phosphorus is "flushed" out of the stream channel and transported downstream.

12. The wide variation in nutrient loadings clearly demonstrates the need to sample more frequently over a wide range of stream flows before a precise identification of nutrient sources can be made.

13. In the Hudson River Basin, wastewater discharge contributes about 73 percent of the phosphorus and 63 percent of the nitrogen.

14. A comparison of sources of nutrients in the Hudson River Basin to those found in the Potomac supports the contention that for large drainage basins in the Middle Atlantic Region the major source of nutrients to the aquatic ecosystem is from wastewater discharges.

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